

EXHIBIT B



US008407273B2

(12) **United States Patent**
Bates

(10) **Patent No.:** **US 8,407,273 B2**
(45) **Date of Patent:** ***Mar. 26, 2013**

(54) **PROCESSING WITH COMPACT
ARITHMETIC PROCESSING ELEMENT**

(75) Inventor: **Joseph Bates**, Lexington, MA (US)

(73) Assignee: **Singular Computing LLC**, Newton, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/399,884**

(22) Filed: **Feb. 17, 2012**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 12/816,201, filed on Jun. 15, 2010, now Pat. No. 8,150,902.

(60) Provisional application No. 61/218,691, filed on Jun. 19, 2009.

(51) **Int. Cl.**
G06F 7/38 (2006.01)

(52) **U.S. Cl.** **708/524; 708/490; 712/221; 382/255**

(58) **Field of Classification Search** None
See application file for complete search history.

(56) **References Cited**

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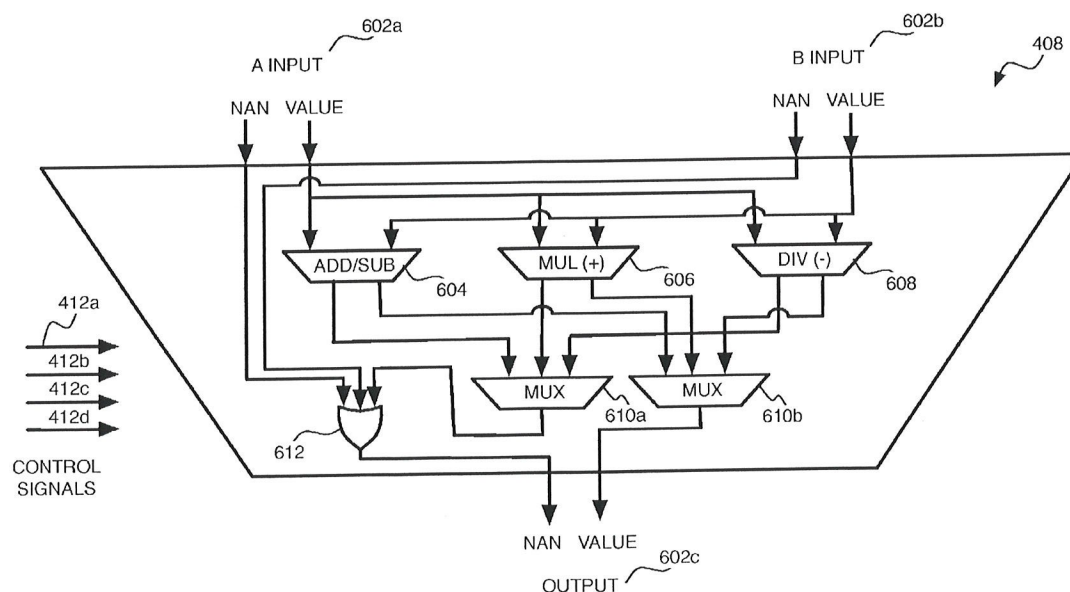
Primary Examiner — Michael D Yaary

(74) Attorney, Agent, or Firm — **Robert Plotkin, P.C.**

(57) **ABSTRACT**

A processor or other device, such as a programmable and/or massively parallel processor or other device, includes processing elements designed to perform arithmetic operations (possibly but not necessarily including, for example, one or more of addition, multiplication, subtraction, and division) on numerical values of low precision but high dynamic range ("LPHDR arithmetic"). Such a processor or other device may, for example, be implemented on a single chip. Whether or not implemented on a single chip, the number of LPHDR arithmetic elements in the processor or other device in certain embodiments of the present invention significantly exceeds (e.g., by at least 20 more than three times) the number of arithmetic elements, if any, in the processor or other device which are designed to perform high dynamic range arithmetic of traditional precision (such as 32 bit or 64 bit floating point arithmetic).

70 Claims, 11 Drawing Sheets





US009218156B2

(12) **United States Patent**
Bates

(10) **Patent No.:** **US 9,218,156 B2**
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(54) **PROCESSING WITH COMPACT
ARITHMETIC PROCESSING ELEMENT**

(71) Applicant: **Singular Computing LLC**, Newton,
MA (US)

(72) Inventor: **Joseph Bates**, Newton, MA (US)

(73) Assignee: **Singular Computing LLC**, Newton,
MA (US)

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(21) Appl. No.: **13/849,606**

(22) Filed: **Mar. 25, 2013**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 13/399,884, filed on
Feb. 17, 2012, now Pat. No. 8,407,273, which is a
continuation of application No. 12/816,201, filed on
Jun. 15, 2010, now Pat. No. 8,150,902.

(60) Provisional application No. 61/218,691, filed on Jun.
19, 2009.

(51) **Int. Cl.**

G06F 7/38 (2006.01)

G06F 7/483 (2006.01)

G06F 7/523 (2006.01)

H03K 19/177 (2006.01)

(52) **U.S. Cl.**

CPC **G06F 7/38** (2013.01); **G06F 7/4833**
(2013.01); **G06F 7/5235** (2013.01); **H03K**
19/17728 (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

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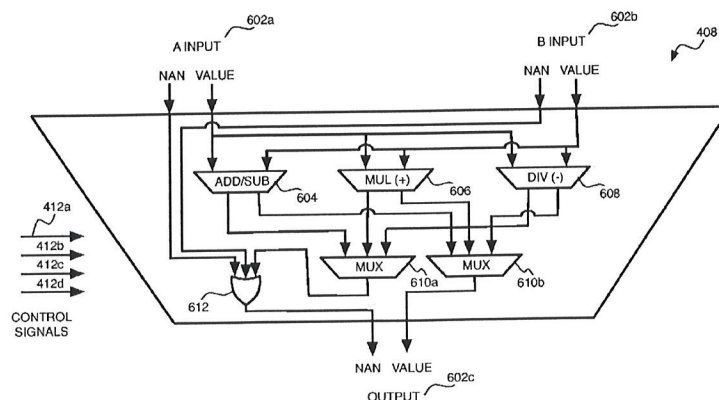
Primary Examiner — Michael D Yaary

(74) *Attorney, Agent, or Firm* — **Robert Plotkin, P.C.; Robert
Plotkin**

(57) **ABSTRACT**

A processor or other device, such as a programmable and/or
massively parallel processor or other device, includes pro-
cessing elements designed to perform arithmetic operations
(possibly but not necessarily including, for example, one or
more of addition, multiplication, subtraction, and division) on
numerical values of low precision but high dynamic range
("LPHDR arithmetic"). Such a processor or other device may,
for example, be implemented on a single chip. Whether or not
implemented on a single chip, the number of LPHDR arith-
metic elements in the processor or other device in certain
embodiments of the present invention significantly exceeds
(e.g., by at least 20 more than three times) the number of
arithmetic elements, if any, in the processor or other device
which are designed to perform high dynamic range arithmetic
of traditional precision (such as 32 bit or 64 bit floating point
arithmetic).

42 Claims, 11 Drawing Sheets





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(12) **United States Patent**
Bates

(10) **Patent No.:** **US 10,416,961 B2**
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(54) **PROCESSING WITH COMPACT
ARITHMETIC PROCESSING ELEMENT**

(71) Applicant: **Singular Computing LLC**, Newton,
MA (US)

(72) Inventor: **Joseph Bates**, Newton, MA (US)

(73) Assignee: **Singular Computing LLC**, Newton,
MA (US)

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patent is extended or adjusted under 35
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claimer.

(21) Appl. No.: **16/175,131**

(22) Filed: **Oct. 30, 2018**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 15/784,359, filed on
Oct. 16, 2017, now Pat. No. 10,120,648, which is a
continuation of application No. 14/976,852, filed on
Dec. 21, 2015, now Pat. No. 9,792,088, which is a
continuation of application No. 13/849,606, filed on
Mar. 25, 2013, now Pat. No. 9,218,156, which is a
continuation of application No. 13/399,884, filed on
Feb. 17, 2012, now Pat. No. 8,407,273, which is a
continuation of application No. 12/816,201, filed on
Jun. 15, 2010, now Pat. No. 8,150,902.

(60) Provisional application No. 61/218,691, filed on Jun.
19, 2009.

(51) **Int. Cl.**
G06F 7/483 (2006.01)
G06F 7/523 (2006.01)

H03K 19/177 (2006.01)

G06F 7/38 (2006.01)

(52) **U.S. Cl.**

CPC **G06F 7/483** (2013.01); **G06F 7/38**
(2013.01); **G06F 7/4833** (2013.01); **G06F**
7/5235 (2013.01); **H03K 19/17728** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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Primary Examiner — Michael D. Yaary

(74) *Attorney, Agent, or Firm* — Blueshift IP, LLC;

Robert Plotkin

(57) **ABSTRACT**

Low precision computers can be efficient at finding possible
answers to search problems. However, sometimes the task
demands finding better answers than a single low precision
search. A computer system augments low precision comput-
ing with a small amount of high precision computing, to
improve search quality with little additional computing.

27 Claims, 11 Drawing Sheets

